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Technical Education in the Big Four: A Factor in Future Competitiveness

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A Research Paper

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A Research Paper

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Issues. Comments and queries are welcome and may
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Competitiveness Division, OGI, [redacted]
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Key Judgments

*Information available
as of 1 September 1985
was used in this report.*

A wide variety of nations, looking to high-technology industries as a source of economic growth and employment, are increasingly focusing on the training of scientific and technical personnel to facilitate the development of these industries. Nowhere has this been more evident than in Japan. Over the last decade Japan—with a population half that of the United States—produced more new engineers than any other non-Communist country. This large pool of technical talent helped transform the Japanese economy into a world-class competitor in high-technology products.

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We believe that Japanese universities will continue to turn out large numbers of scientific and engineering personnel for the foreseeable future. Shortages of appropriately trained Ph.D.-level scientists and engineers, however, could limit Japan's efforts to become a world leader in new technologies. Japan produces few of the doctoral engineers and research-quality scientists that will be crucial to building basic research capabilities. Recognizing this shortfall, Japanese industry probably will step up its current efforts to recruit US- and European-trained Ph.D.'s to conduct and direct research efforts. Nonetheless, over the long haul, lack of research-caliber personnel is likely to be a major hurdle in Japan's efforts to continue to improve its relative competitiveness in cutting-edge technologies.

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West Germany may face across-the-board shortages of new scientists and engineers during the next 10 to 15 years, chiefly because of rapid declines in the student-age population. As a result, West German industrial, research, and military potential could suffer from shortages of science and engineering personnel during the 1990s. The potential decline in the stock of technical personnel is compounded by problems in fully utilizing existing employees. A weak entrepreneurial tradition, legal and cultural barriers to forming companies, restrictions on hiring and firing, and low worker mobility inhibit aggressive use of technical manpower.

France, by contrast, probably will continue to expand its stock of scientists and engineers during the foreseeable future because of stable growth in the youth population and continued student interest in technical subjects. Competition for the best schools will remain intense, and there will be pressures to expand university capacity to accommodate more students. Like West Germans, however, most French graduates seek sinecures after graduation, and there are few entrepreneurs pushing new product

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and marketing in the high-technology fields. From the point of view of quality and quantity of technical personnel, France stands a good chance of improving its technical capabilities during the next decade, particularly vis-a-vis West Germany.

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As for the United States, the shrinking youth population has sparked fears of shortages of scientists and engineers; these fears appear to be largely exaggerated. According to recent trends, a growing proportion of new students are entering the engineering fields. If this trend continues, it will mean engineering enrollments will continue to strain university capacity for the next 15 years. The number of new scientists, however, quite likely will decline through the end of the decade and, if waning student interest is not reversed, prospects are poor for substantially increased enrollments in the physical sciences during the 1990s. A potentially more serious concern arises from the declining student interest in graduate science and engineering programs, largely because of the strong demand for bachelor of science engineers and the consequent lack of incentives to pursue advanced degrees. Fewer numbers of Ph.D.-level students could adversely affect the staffing of research and education posts and basic research output in the next decade.

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The high quality of US academic institutions continues to draw increasing numbers of foreign students—particularly at the graduate level. Indeed, almost half of all US engineering Ph.D.'s awarded in recent years have gone to foreigners, and 25 percent of all US Master of Science students are foreign citizens. Of the 14,000 Japanese studying on US campuses in 1984, for example, nearly one-third were in graduate programs. A National Science Foundation survey indicated that half of the foreign science and engineering Ph.D. recipients return home to work. Traditionally, foreign enrollments have not been a constraint on US academic institutions' ability to educate American students. Recently, however, faculty shortages and limited university capacity—particularly in the most prestigious schools—have forced some institutions to cap enrollment in some engineering fields.

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Technical Education in the Big Four: A Factor in Future Competitiveness

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Introduction

Many countries view high-technology industries as a major source of employment and economic growth and have pursued various policies to promote the development of these sectors. Success in these industries, however, requires a well-trained cadre of scientists and engineers. As other nations increase their high-technology capabilities, both US Government officials and businessmen are concerned that the United States may not be producing the quantity and quality of human resources needed to meet the competitive challenges from abroad.

greatest during 1975-77 when Japanese universities awarded an average of nearly 61,000 second-cycle engineering diplomas each spring, compared with 40,000 in the United States. Engineering graduations in Japan stabilized in the late 1970s because of losses in the college-age population, and the United States overtook Japan in the graduation of new baccalaureate engineers in the early 1980s.

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Trends in Science and Engineering Graduates

The United States, Japan, France, and West Germany all have added to their respective stocks of engineers and scientists over the past three decades; however, each has experienced differences in the growth and types of degrees conferred. Japan has led in the growth of second-cycle engineers,¹ with gains most rapid in the 1960s before slowing in the last five years. The United States experienced a fall in numbers of baccalaureate engineers in the 1970s, but an upward swing has started recently. Although the number of each country's scientists has not been rising as rapidly as that of engineering graduates, the United States has graduated more advanced degree engineers and scientists than the other countries and, in terms of sheer numbers, has a larger stock on which to draw for research and development, especially fundamental research.

In contrast, West Germany and France confer far fewer second-cycle engineering diplomas than either the United States or Japan. In 1975, for example, West Germany produced more than 21,000 engineering *diploms* and France awarded some 8,000 *diplomes d'ingenieurs*; by 1982, the total had increased slightly to 23,000 and 10,000, respectively.² The United States awards about three times as many graduate engineering diplomas each year as Japan. West Germany and France have no equivalent Master's programs, but West Germany produces nearly as many doctoral engineers as the United States; France graduates only about one-fifth that number annually. The US statistics are somewhat misleading, however, because of the large number of foreign students in US schools. Of the 2,500 engineering Ph.D.'s awarded in 1979, for example, 47 percent went to foreigners; one-fourth of all full-time US Master of Science (M.S.) degree students that year also were foreign citizens. A National Science Foundation (NSF) survey of foreign science and engineering Ph.D. recipients found that half of these graduates return abroad to work.

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Engineers. Japan, with a population half that of the United States, graduated more second-cycle engineers during the last decade than any other non-Communist country. Japanese universities conferred more than 52,000 baccalaureate engineering degrees in 1970, compared with 45,000 in the United States (table 1). The lead widened throughout the early 1970s and was

Scientists. In the physical sciences, the United States is awarding about 25,000 baccalaureate degrees each year, and Japan and West Germany produce about 9,000 and 8,000 second-cycle graduates, respectively (table 2). France records nearly 16,000 second-cycle

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¹ Second-cycle diplomas are baccalaureate-level university degrees; first-cycle degrees are postsecondary diplomas below the Bachelor of Science level; third-cycle are graduate degrees.

² Some researchers consider French graduates of engineering schools to be third-cycle degree holders. By this convention, there are no French equivalents to US Bachelor of Science engineers.

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Table 1
Big Four: University Engineering Graduates, 1960-82

	1960	1965	1970	1975	1980	1982
United States						
Second cycle						
Bachelor	37,808	36,795	44,772	40,065	59,240	66,990
Mechanical	9,566	7,984	9,247	6,890	11,808	16,200
Electrical	10,617	11,697	12,225	10,161	13,821	12,400
Third cycle						
Master	7,159	12,056	15,597	15,434	16,846	18,543
Ph.D.	794	2,074	3,434	3,002	2,479	2,887
Japan						
Second cycle						
Bachelor ^a	19,239	31,173	52,383	60,316	65,548	65,930 ^b
Mechanical ^c	NA	NA	11,502	13,244	13,766	13,982 ^b
Electrical ^c	NA	NA	13,491	15,534	17,187	17,574 ^b
Third cycle						
Master	NA	2,272	4,448	5,821	7,200	7,363
Ph.D.	NA	419	853	986	1,200	621
West Germany						
Second cycle						
<i>Diplom</i> (universities)	3,228	5,450	4,156	4,603	6,689	7,000 ^b
Mechanical	1,109	1,036	1,136	1,399	1,928	2,425 ^b
Electrical	669	810	1,008	1,294	1,785	1,950 ^b
<i>Diplom</i> (polytechnics)	NA	NA	NA	16,764	16,227	16,050 ^b
Mechanical	NA	NA	NA	6,653	5,998	6,300 ^b
Electrical	NA	NA	NA	4,819	4,911	4,350 ^b
Third cycle						
Doctor	1,129	1,276	1,996	2,312	2,503	2,500 ^b
France						
Second cycle						
<i>Diplomes d'ingenieurs</i> ^d	NA	7,649	9,077	7,935	8,737	9,960 ^b
Mechanical	NA	445	593	1,360	1,466	1,522 ^b
Electrical	NA	985	828	1,503	1,661	1,694 ^b
Third cycle						
<i>Doctor d'etat</i>	NA	216	256	470	500 ^b	NA

^a New university baccalaureate degree recipients entering employment plus five-year technical school graduates.

^b Estimated.

^c Estimated from enrollment.

^d Does not include agriculture and food science engineers.

Sources: National Science Foundation, National Center for Education Statistics, statistical abstracts, and other country sources.

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Table 2
Big Four: University Science Graduates, 1960-82

	1960	1965	1970	1975	1980	1982
United States						
Second cycle (B.S.)						
Physical science	16,057	17,916	21,555	20,896	23,661	24,500 ^a
Math ^b	11,437	19,669	29,109	23,385	22,686	26,450 ^a
Life sciences ^c	24,141	34,642	52,129	72,710	71,617	68,000 ^a
Third cycle (M.S.)						
Physical sciences	3,387	4,918	5,948	5,830	5,233	5,325 ^a
Math ^b	1,765	4,294	7,107	6,637	6,515	6,800 ^a
Life sciences ^c	3,751	5,978	8,590	9,618	10,278	9,750 ^a
Third cycle (Ph.D.)						
Physical sciences	1,861	2,865	4,403	3,710	3,149	3,225 ^a
Math ^b	291	685	1,225	1,147	962	960 ^a
Life sciences ^c	1,660	2,539	4,165	4,402	4,716	4,800 ^a
Japan						
Second cycle (B.S.)						
Physical sciences ^d	3,053	4,143	5,772	7,074	8,936	NA
Math	NA	NA	1,439	1,793	2,324	NA
Chemistry, biology	NA	NA	1,734	1,714	2,738	NA
Third cycle (M.S.)						
Physical science	NA	932	1,484	1,482	1,719	NA
Math	NA	NA	NA	NA	NA	NA
Chemistry	NA	NA	282	424	495	NA
Third cycle (Ph.D.)						
Physical science	NA	416	611	676	900	NA
West Germany						
Second cycle (Diplom) ^e						
Math and science	1,239	2,065	2,891	6,070	7,506	8,300 ^a
Physics	371	976	1,180	1,278	1,080	1,250 ^a
Chemistry	741	724	951	1,257	1,195	1,500 ^a
Third cycle (Doctor)						
Math and science	1,129	1,276	1,996	2,312	2,503	2,500 ^a
France						
Second cycle						
License in science	NA	6,356	6,265	7,228	6,582	NA
Maitrise in science	NA	NA	7,127	6,387	9,067	NA
Third cycle						
Doctorat in science	NA	764	1,467	1,851	2,009	NA
Doctor d'etat in science	NA	547	1,043	1,144	1,111	NA

^a Estimated.^b Math, computer science, and statistics.^c Biology, agriculture, and medicine.^d Estimated from enrollment.^e Includes fachhochschule (polytechnic) graduates in 1975 and later years.

Sources: National Science Foundation, National Center for Education Statistics, statistical abstracts, and other country sources.



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science degrees annually, but this total includes biologists, oceanographers, and other environmental and life scientists that are not included in the other countries' statistics. Japan and West Germany each grant fewer than one-fourth as many math degrees as physical science degrees, while math baccalaureate degree recipients in the United States outnumbered physical science graduates by about 2,000 in 1982. []

The United States also leads in third-cycle scientific certification; more than 8,000 physical science graduate degrees were granted last year, and nearly as many graduate math degrees. Japan, West Germany, and France each turn out about 3,000 or fewer third-cycle science degrees in all science fields, but the numbers have been increasing. []

The Differing Quality of Education

Counting numbers of graduating engineers and scientists gives only a partial picture of a nation's scientific and technological (S&T) manpower resource base. Differences among countries must be considered in terms of comparability of training, breadth and depth of subjects covered, and degree of job flexibility provided by training. In addition, the role of industry in providing further training and education must be taken into account along with cultural characteristics and business practices that can influence the S&T manpower base. []

Japan. Japanese university training in engineering emphasizes basic technique and application over creativity and design—more like technical or apprenticeship training in the United States and Western Europe than university training. Japanese engineering schools are highly structured and require that most work be done in class in a group environment, compared with schools in the United States, which stress independent study. []

In part because of these shortcomings, Japanese employers frequently provide substantial additional education for a new employee with a Bachelor of Science degree:

- Hitachi, for example, has a two-year training program at the Hitachi Institute of Technology for new engineers.

- Nippon Electric provides continuing education at its Institute for Technical Education.
- Virtually all of Matsushita's 120,000 employees have had substantial company training at their Research and Training Institute.

Although this additional training closes some of the educational gap between Japanese engineers and their US or West European counterparts, it does not provide the breadth associated with advanced university training in the West. []

Relatively few Japanese continue their formal education beyond the Bachelor level. Of those that do, the brightest and most capable are usually sent by their employers to schools in the United States. More than 14,000 Japanese were studying on US campuses in 1984; nearly one-third of them were in graduate programs. Moreover, many research grants from Japanese corporations to US universities also stipulate the involvement of Japanese personnel. Under Nippon Telegraph and Telephone's (NTT) research contract with the Massachusetts Institute of Technology (MIT), for example, two of NTT's scientists will be rotating to MIT's media lab annually for the next five years to learn about computer voice recognition and synthesis. These types of arrangements provide valuable basic research skills for Japanese scientists and engineers and access to cutting-edge technology before the results reach technical journals. []

West Germany and France. Technicians play a much larger role in West European science and engineering labor forces than in the United States or Japan; only about one-third of the West German and French "engineers," according to an NSF study, have the equivalency of a US baccalaureate degree (see inset). Vocational students train for particular trades or crafts and usually remain in the same occupation, and often the same firm, until retirement. In both West Germany and France, work proficiency among technicians is consequently high. However, well-trained technical workers in these countries tend to be less flexible in adapting to rapidly changing technologies because their training system focuses on specific, standardized skills. Because West German and French graduates of two-year technical schools often hold jobs that would be held by second-cycle

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Big Four: Relative Value of Academic Degrees

To determine the relative value of academic credentials among the major industrial countries, we pooled information on the length of time spent earning each degree, the opinions of educators on the quality of instruction and laboratory equipment, and evaluations by employers of the productivity and work

habits of new graduates. Most experts cautioned that the value of US diplomas appears to be falling relative to the other countries studied primarily because of equipment and staffing problems in US universities: ^a

United States		Japan		West Germany		France	
Associate Degree	50	Junior College	50	State Technician	70	Science preps	50
						DUT and BTS	70
Bachelor of Science	100	Technical Colleges, B.S.	95	Ingenieur (grad.)	90	License	90
				Diplom	110	Maitrise	110
Master of Science	120	Master of Science	115			Diplome d'ingenieur	150
Doctor of Philosophy	200	Doctor of Philosophy	150	Doctor	200	Doctorat	180
						Doctor d'Etat	200

^a The US Bachelor of Science degree is the base diploma and is set equal to 100. An Associate Degree requires only half the number of years to obtain, so it is valued at 50. Similarly, a Master's degree is valued at 120, and a Ph.D. at 200. For the foreign countries, US professors and researchers were asked to compare the various degrees and degree holders with their nearest US equivalents.

engineers in the United States or Japan, relatively fewer university-trained engineers and scientists are required to fill industry's needs. [redacted]

Second- and third-cycle scientists and engineers in West Germany and France are roughly equivalent to their US counterparts despite several notable weaknesses in the academic and research environment of Western Europe:

- An antiquated education system that has favored upper- and middle-class offspring makes it difficult for children of working-class families to receive university training. West Germany has taken steps to change this system in the past 15 years by making it easier for youth to switch school tracks later in the education process.
- The "don" system of graduate training encourages elitism at the expense of flexibility and creativity. While graduates are usually well trained, they are

limited to some extent by the interests and shortcomings of their mentors. This system can be particularly stultifying in a world of rapidly changing technologies.

- The publish-or-perish requirement prevalent in US universities and laboratories is much weaker in Western Europe. This lack of pressure inhibits the spread of information and promotes duplicative research efforts.

- West European universities often lack close ties to industry. [redacted] industry is particularly dissatisfied with universities in West Germany; industry believes that universities react too slowly to labor market needs, and that syllabuses are too technical and fail to foster innovativeness and creativity among graduates.

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Nevertheless, in West Germany and France, faculty recruitment at universities is easier than in the United States because of the higher prestige and salaries associated with the teaching profession. [REDACTED]

The Outlook for Supply and Demand Through 1995

The extent to which the scientific and engineering talent affects a nation's science and technology potential hinges both on projected supply as well as on the demand for trained scientists and engineers. These supply and demand factors, in turn, depend on demographic trends, educational facilities, and expected growth of industries requiring highly trained engineers and scientists. [REDACTED]

Supply. Compared with the recent past, the demographic potential for new scientists and engineers over the next 10 to 15 years is much greater in Japan than in the other industrial countries. Japan's current large cohort of 5- to 20-year-olds will provide an expanding pool of college-age youth through 1995 (figure 1). France is likely to see little change in the foreseeable future because of the unusually even age distribution of its youth population. In contrast, the United States now has fewer young people in the 15 to 19 age group than in ages 20 to 24, and still fewer in ages 10 to 14. Consequently, the declines in the US youth population observed since the early 1980s will continue for the next several years. Similarly, West Germany will experience losses in the number of university-age people through 1995 after witnessing tremendous growth in that age group during 1976-85. [REDACTED]

Recent trends in second-cycle engineering enrollment, however, show a decline in the rate of student participation in Japan and rising in the United States, West Germany, and France:

- In Japan, the share of students enrolling in engineering programs has been falling by nearly 2 percent each year since the mid-1970s. The rapid pace at which graduates have been turned out has led to a surplus and subsequent underemployment of baccalaureate-level science and engineering graduates in Japan.
- In West Germany and France, undergraduates have been switching to engineering programs from other

disciplines at an average rate of 1.5 and 3 percent each year, respectively, for about the past 10 years.

- In the United States, where entry-level engineering salaries are well above average, student participation in Bachelor of Science engineering programs has grown by more than 5 percent each year since the mid-1970s. [REDACTED]

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Student interest in graduate engineering programs has been disparate, largely because of differing patterns of demand for second- and third-cycle engineers. In Japan and France, the proportion of engineering students remaining in school to complete third-cycle studies has been stable since the mid-1970s. Student participation in doctoral engineering studies in West Germany has grown rapidly in the past decade. In the United States, enrollment in third-cycle studies has dipped because of a strong demand for Bachelor of Science degree holders and the lack of economic incentives to pursue advanced degrees. [REDACTED]

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In the scientific area, the trends are the reverse of the engineering area. The share of students enrolled in second-cycle natural science curriculums has slipped in the United States, West Germany, and France. In Japan, however, there are proportionally as many science students at both the second- and third-cycle as there were 10 years ago. In graduate science programs, student participation has been stable in France, rising in West Germany, and declining in the United States. [REDACTED]

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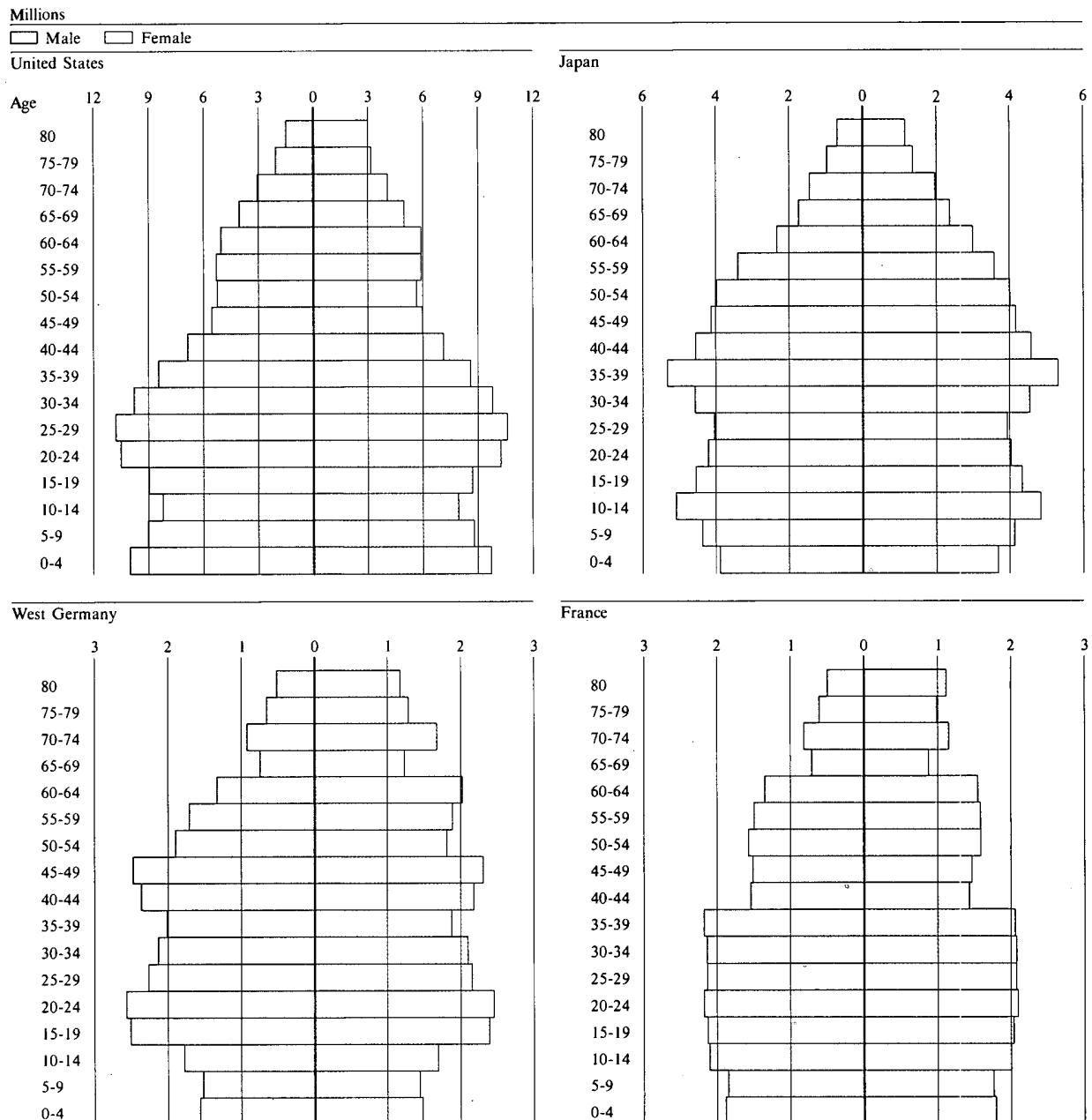
Table 3 provides a rough indication of future enrollment based on demographic projections and changing enrollment trends. In Japan, growth in student-age population probably will swell engineering enrollment through 1995 despite a declining proportion of new students entering engineering fields; science enrollment probably will grow even more quickly. Growth in second-cycle engineering enrollment in West Germany probably will slow over the next few years, despite increased student interest in engineering, because of the declining numbers of teenagers and young adults. Declining student participation in science programs, coupled with the shrinking student-

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Figure 1
Big Four: Age Distribution of Population, 1985



Source: United Nations, *Demographic Indicators of Countries*, 1982

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	1975	1980	1985 ^b	1990 ^b	1995 ^b
United States					
Youth population (15-24)	40,244	41,761	38,403	34,181	34,680
Total enrollment	8,728	9,387	8,948	8,272	8,670
Science	128	134	124	112	114
Engineering	393	541	671	794	1,075
Japan					
Youth population (15-24)	17,162	16,242	17,120	18,780	18,374
Total enrollment	1,586	1,742	2,123	2,718	3,087
Science	50	55	67	86	98
Engineering	317	318	356	414	430
West Germany					
Youth population (15-24)	8,707	9,468	9,918	8,350	6,411
Total enrollment	790	970	1,146	1,086	939
Science	75	151	169	151	124
Engineering	137	176	224	228	212
France					
Youth population (15-24)	8,484	8,504	8,433	8,244	7,677
Total enrollment	893	1,018	1,148	1,275	1,350
Science	117	130	143	154	159
Engineering	112	150	198	257	319

^a Total enrollment is the number of students enrolled in universities and technical colleges; science and engineering enrollment includes all second-cycle enrollment in these subjects.

^b Future enrollment is forecast on the basis of UN demographic projections and historical enrollment trends. Student participation in higher education and in science and engineering departments is expected to grow or decline at the same rates that it did during 1975-80. In the United States, the share of the youth population continuing their education in universities grew at an average annual rate of 0.7 percent; the share of these students enrolling in natural science curriculums declined by 0.6 percent annually, and the share in engineering grew by 5.2 percent each year. In Japan, the annual percent changes were 3.0, 0.06, and -1.8 for total, science, and engineering enrollment, respectively. In West Germany: 2.4, -1.1, and 1.4. In France: 2.6, -0.6, and 3.2.

age population, probably will further reduce future science enrollments. French engineering departments probably will continue adding new students at a fast clip because of the shift toward engineering education; science enrollment will grow at a more modest pace. The United States faces continued high student

interest in engineering programs that probably will outweigh the decline in numbers of youth; science enrollment, however, is likely to continue to slip.

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Resource constraints in universities may limit the actual output of science and engineering graduates. Faculty shortages and limited university capacity—particularly in the most prestigious schools—probably will inhibit the growth in engineering enrollment in both France and the United States in the near future. The United States has already experienced faculty shortages in recent years, particularly engineering faculty, and many universities have capped enrollment in engineering fields. Unless these constraints are eased, it is unlikely that enrollment will be able to grow at the same pace it did during 1976-80. West Germany, which experienced faculty and space shortages in the 1970s, will have fewer problems during the next 10 years because of the rapidly declining numbers of youth. Japanese universities may have difficulty finding enough room for the projected surge in enrollments during 1986-90; competition for university placement will intensify during these years but probably will slack off after the mid-1990s. []

Demand. Industry is the primary employer of science and engineering graduates. The percentage of technical workers employed in industrial concerns ranges from about 75 percent in the United States to more than 90 percent in Japan; about 5 percent are in education in each country, and the remainder are in government or are self-employed. The majority of doctoral scientists and engineers either teach or are involved in conducting or directing research. Second-cycle degree holders can be found in almost any environment, depending on individual skills, experience, and career goals. First-cycle workers are needed in all technical environments to do surveying or drafting, to aid research, to perform experiments, and to provide assistance for science and engineering professionals. []

[] employment opportunities in high-technology manufacturing probably will grow at above-average rates in each of the Big Four countries during the next 10 years.³ Positions in knowledge-

[] Department of Commerce definitions to project total employment in different sectors of the various economies. The model used for the projections related high-technology employment to total employment, industrial production, manufactured goods, exports, domestic gross fixed investment, and labor productivity. Because the data include all employees, not only scientists and engineers, the results are better indicators of general trends in employment rather than estimates of science and engineering employment growth. []

intensive industries in West Germany and France are projected to grow by about 1.5 percent annually for the next 10 years, while overall jobs growth is projected to be less than 0.5 percent each year. The number of jobs in these industries in the United States and Japan is forecast to increase by about 2.2 and 1.1 percent each year, respectively, which is only slightly faster than projected total employment growth rates. []

Part of the services sector—communications, transportation, and finance—also will provide expanding employment opportunities for science and engineering personnel. Although many of these firms are not considered high technology, they still need scientists and engineers for many of their activities. Other science and engineering positions will be included in the general heading of services but will provide consulting services, customized programming, or design work related to high technology. Employment in the service sector probably will continue growing at a faster pace, on average, than employment in manufacturing throughout the industrial countries. []

Growth of R&D opportunities in the developed countries probably will continue to be faster than average as government and industry attempt to develop and harness new technologies. The United States and Japan have relatively more scientists and engineers engaged in R&D than West Germany or France—about 64 and 56 per 10,000 labor force members, respectively—compared with 48 in West Germany and 32 in France. Science and engineering employment in R&D has grown fastest in West Germany and the United States since the mid-1970s. []

Projections of employment growth by occupation are not available for Japan, West Germany, or France, but Bureau of Labor Statistics (BLS) forecasts of US occupational trends probably are broadly applicable to all industrial countries. These projections indicate that the majority of the 10 fastest growing occupations through 1995 will be computer related and include service technicians, system analysts, programmers, computer operators, office machinery repairers, and peripheral data-processing equipment operators. In the United States, employment of computer specialists is forecast by BLS to grow at an average annual rate of 4.8 percent through 1995. Electrical

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engineers also are included among the top 10 employment growth fields, and mechanical engineers are counted in the top 20; demand for these occupations is projected to grow by 4.1 and 3.5 percent each year, respectively, for the next 10 years. [REDACTED]

Potential Shortfalls

West Germany is most vulnerable to across-the-board shortages of science and engineering personnel during the next 10 years. The dramatic decline in the number of youth probably will mean a steady falloff in enrollment in science and engineering curriculums through 1995. The slowdown in the number of new graduates means that the stock of West German science and engineering personnel will be growing more slowly through 1990 and may decline during the next decade. [REDACTED]

We believe that the supply of science and engineering talent in the other industrial countries probably is sufficiently flexible to meet demand. The exodus of line personnel into management, sales, or staff positions can be slowed with economic incentives, individuals trained in related specialties can be retrained, and technicians can absorb the burden of routine tasks to free existing scientists and engineers for more creative endeavors. Most important, sectors with the fastest growth rates and highest profits—presumably the more knowledge-intensive sectors—can hire technical workers away from less profitable industries. [REDACTED]

However, in selected areas or under certain conditions, shortages could emerge in the United States and Japan. In Japan there are already insufficient numbers of trained Ph.D.'s to properly staff R&D facilities, and efforts by government and industry to expand basic research will exacerbate these shortages. Press reports of increased usage of women, minorities, and foreigners—even on temporary contracts—indicate the need by generally parochial Japanese companies for appropriately trained researchers. In the United States, proposed defense projects may induce a shortage of certain types of scientists and engineers; BLS simulations of the US economy demonstrate that shortages of computer scientists and electrical engineers are likely in the event of an emergency mobilization. [REDACTED]

Implications

The competitive challenge from Japan is unlikely to suffer from any weaknesses in science and engineering education. A strong emphasis on math and science in secondary schools⁴ and in engineering at the university level has made an impact at the workplace and in world markets for the past 25 years. The emphasis on technical education over legal and business training has helped transform the Japanese labor force and subsequently the economy into a world-class competitor in high-technology products. Japanese universities probably will continue turning out more B.S.-level engineers for their labor force size than the United States for the foreseeable future. [REDACTED]

Japan's effort to develop cutting-edge research capabilities and dominate the high-technology market of the future probably will, however, be limited by a lack of appropriately trained personnel. Despite the highest ratio of engineers per capita among the industrial countries, Japan produces few third-cycle engineers and even fewer research-quality scientists. The expected rapid growth of second-cycle graduates probably will tax university capacity and industry's ability to absorb them, especially if managers pursue foreign or foreign-trained Japanese researchers to lead the R&D drive. [REDACTED]

In West Germany and France, the quality of scientists and engineers is unlikely to be the limiting factor in improving the relative technical capabilities of these countries during the next several years. Rather, the environment in which they operate may limit their effectiveness. There is, for example, a weak entrepreneurial tradition in Western Europe; top university graduates in both West Germany and France seek positions in government and large conservative corporations where they tend to be insulated from market forces. Moreover, West Germany faces a potential

⁴ Although an analysis of preuniversity education is beyond the scope of this paper, the National Science Foundation contends that among the Big Four secondary education in the United States is worst; academic diplomas in West Germany, France, and Japan are considered approximately equivalent. Appendix B describes schools and diplomas in each of the foreign countries. [REDACTED]

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decline in the stock of scientists and engineers during the next decade. If demand for technical personnel continues to grow—or even remain steady—West German firms will be under pressure to hire substantial numbers of non-German scientists and engineers after 1990. West German industrial, research, and military capabilities could suffer from these shortages during the next decade. [REDACTED]

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The United States faces several challenges in science and engineering education over the next 10 years that will affect future competitiveness:

- Poor secondary school preparation in math and science, according to the NSF, keeps many people from attempting technical fields of study and increases the need of remedial postsecondary training of those that do.
- Flagging student interest in graduate science and engineering training could adversely affect the staffing of research and education positions and basic research output in the 1990s.
- The large proportion of foreign students in US science and engineering departments—especially graduate students—channels educational resources to individuals who may not work in the United States, and who, in any event, cannot work in defense-related jobs.

Nonetheless, fears of general shortages of scientists and engineers arising from a shrinking student-age population appear to be largely exaggerated. A growing proportion of new students is entering the engineering fields. If this trend continues, it will mean continued growth in engineering enrollment for the next 10 to 15 years. The number of new scientists, however, likely will decline through the end of the decade and, if waning student interest is not reversed, prospects are poor for substantially increased enrollments in the physical sciences during the 1990s. [REDACTED]

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Appendix A

Science, Engineering, and
Technical Graduates

By relative labor force size, Japan's lead in training second-cycle engineers—about 12 for each 10,000 people in the labor force—is clear; France trails with about four; West Germany and the United States are in between with approximately eight and six, respectively (figure 2). In graduate degree production, the United States leads on a per-worker basis with about two additional Master of Science or Doctor of Philosophy recipients each year per 10,000 labor force members, Japan produces about 1.5, and West Germany and France each turn out considerably fewer than the United States or Japan. Comparing doctoral recipients alone, however, West Germany graduates about as many engineers for its labor force size as the other countries combined.

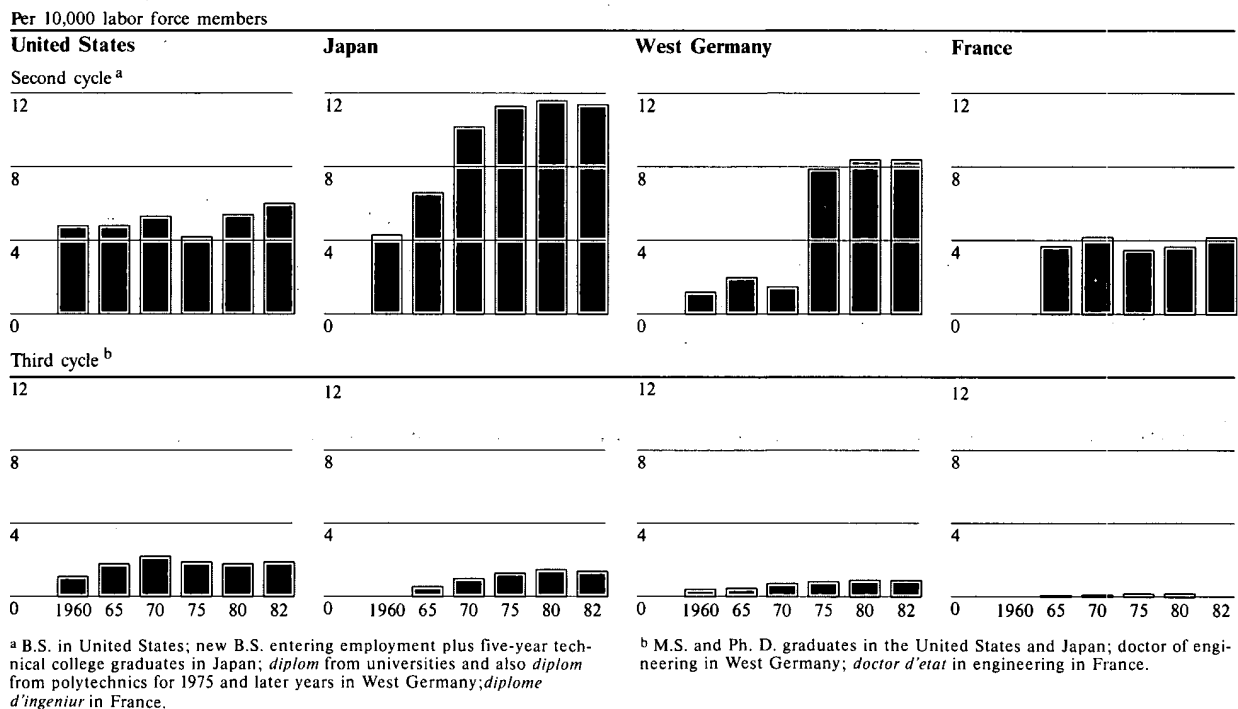
West Germany leads with more than three new second-cycle scientists per 10,000 workers annually, with the United States and Japan following with about two. France produces nearly seven graduates per 10,000 labor force members, but French data include natural sciences and overstate the number of physical scientists alone. The number of second-cycle science degrees is rising in Japan and West Germany while it is more or less stable in France and the United States (figure 3). France leads in third-cycle science graduates on a per capita basis, with about 1.5 doctorates for each 10,000 labor force members; the United States and West Germany each granted fewer than one; and Japan about 0.5.

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Figure 2

Big Four: Engineering Graduates, 1960-82

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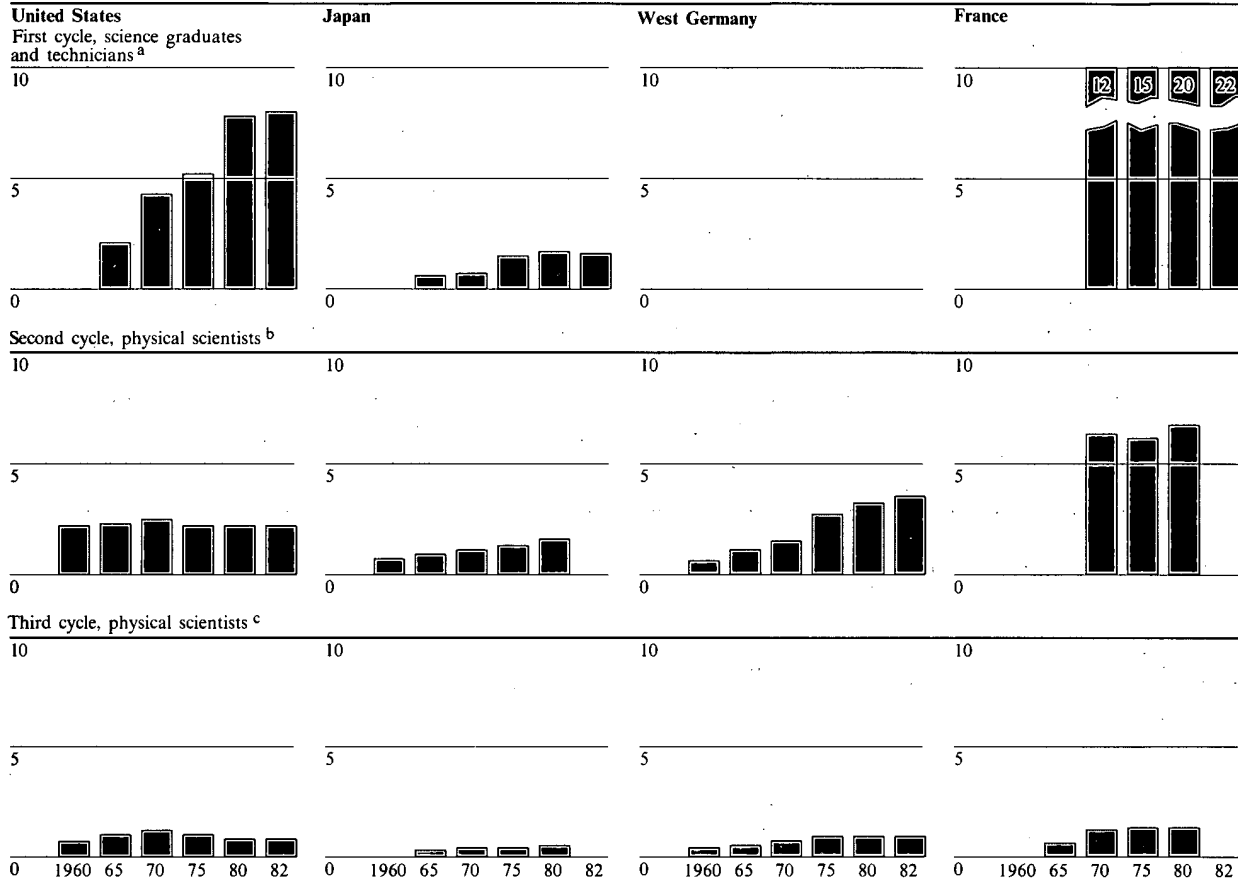
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Figure 3
Big Four: Science and Technical Graduates, 1960-82

Per 10,000 labor force members



^a Technical associate degree in the United States and Japan; various science and technical diplomas in France (see table 3 for details).

^b Bachelor degrees in the United States and Japan; *diplom* in mathematics and science from universities and also *diplom* from polytechnics for 1975 and later years in West Germany; *licence* and *maitrise* in science in France.

^c M.S. and Ph.D. in the United States and Japan; doctors in West Germany; and *doctorat* and *doctorat d'etat* in France.

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The relative importance of first-cycle graduates in the industrial countries is growing as indicated in figure 3. France now graduates about 30 first-cycle persons per 10,000 labor force members, compared with eight in the United States and less than two in Japan (table 5). About one-half of the French graduates are

receiving technical diplomas; the other half are general science majors who plan to continue on to university training. West Germany, too, has numerous technical and vocational graduates, but comparable numbers are not available.

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Table 4
Big Four: First-Cycle Science,
Engineering, and Technical Graduates, 1965-82^a

	1965	1970	1975	1980	1982
Total	NA	46,794	54,964 ^b	72,980	75,838 ^b
United States					
Associate degrees ^c	16,190 ^b	36,644	50,111	85,192	90,000 ^b
Japan					
Junior college ^d	3,110	6,387	7,830	9,441	9,274
West Germany	NA	NA	NA	NA	NA
France					
DEUG in sciences ^e	NA	12,004	7,692	9,284	NA
DUT ^f	NA	3,154	14,746	19,769	NA
Two-year BTS ^g	NA	10,740	11,526	17,442	18,500
Science preps ^h	19,732	20,896	21,000	26,485	27,838

^a Postsecondary degrees and certificates below bachelor level.

^b Estimate.

^c Associate degrees in data processing, mechanical and electrical engineering, and natural science technologies.

^d Mechanical and electrical engineers plus applied chemistry graduates estimated by enrollment.

^e *Diplome d'etudes universitaires generales*, a two-year university degree.

^f *Diplome universitaire de technologie*, a two-year technical school degree.

^g *Brevet de Technicien Supérieur*, a two-year technician's certificate.

^h *Grandes ecoles*, two-year science preparatory programs.

Sources: National Science Foundation, National Center for Education Statistics, statistical abstracts, and other country sources.

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Appendix B

Patterns of Education in Japan, West Germany, and France

Japan. Compulsory schooling in Japan begins at age six and continues through either junior high or the end of the school year under way when the pupil turns 15. Nearly 95 percent of junior high graduates go on to senior high schools, however, compared with barely half during the late 1950s. University attendance is determined solely by the results of comprehensive examinations (Joint Achievement Tests) taken during the senior year of high school; since university status is the major determinant of future employment, the university entrance exam has become the focal point of the educational system in Japan. [REDACTED]

Elementary schools provide the most diverse curriculums among Japanese schools. In addition to the basic subjects, pupils are taught calligraphy and learn to play one or two simple musical instruments. Physical education is stressed, and pupils are expected to achieve specified skill levels at each grade. Conformity and group consciousness are important; and children are automatically passed through the six elementary grades, regardless of their mastery of the materials, to maintain the social harmony of the class. [REDACTED]

In junior high school, preparation begins in earnest for the examination that will determine the student's choice of senior high schools. Each year the Japanese media publish lists of high schools with the best records in placing students at Tokyo University, and competition for these schools is keen. Classes are fast-paced and center around lectures taken directly from texts—classroom participation and discussion are not common. Students often continue their studies outside of school with the help of tutors to improve their score on the senior high school entrance exams. [REDACTED]

In the better senior high schools—the Hibiya Public High School in Tokyo, for example, which virtually assures graduates of university placement—the prescribed curriculum is covered in two years and the third is devoted to review of old tests. Schools concentrate on subjects covered by the examination—

Japanese, mathematics, social studies, science, and English—and course options are rare. The key to examination success is memorization, reflecting the Confucian tradition that education is the conveyance of factual knowledge, while critical or interpretive thinking is largely ignored. Most students take special “cram” courses in the evenings, and students who fail the university exam may spend another year in special schools preparing for the next one. [REDACTED]

The stature of the university is paramount in determining future employment. At the top of the hierarchy is Tokyo University, whose graduates accounted for about 40 percent of the presidents of companies listed on the first section of the Tokyo Stock Exchange last year. Another 40 percent came from the next four most popular universities: Keio, Kyoto, Waseda, and Hitotsubashi. A survey by the *Far Eastern Economic Review* showed Tokyo University graduates holding 88.6 percent of posts ranked section chief or higher in the Ministry of Finance, 76 percent in Foreign Affairs, 73.5 percent in the National Land Agency, and 68.5 percent in Transportation. [REDACTED]

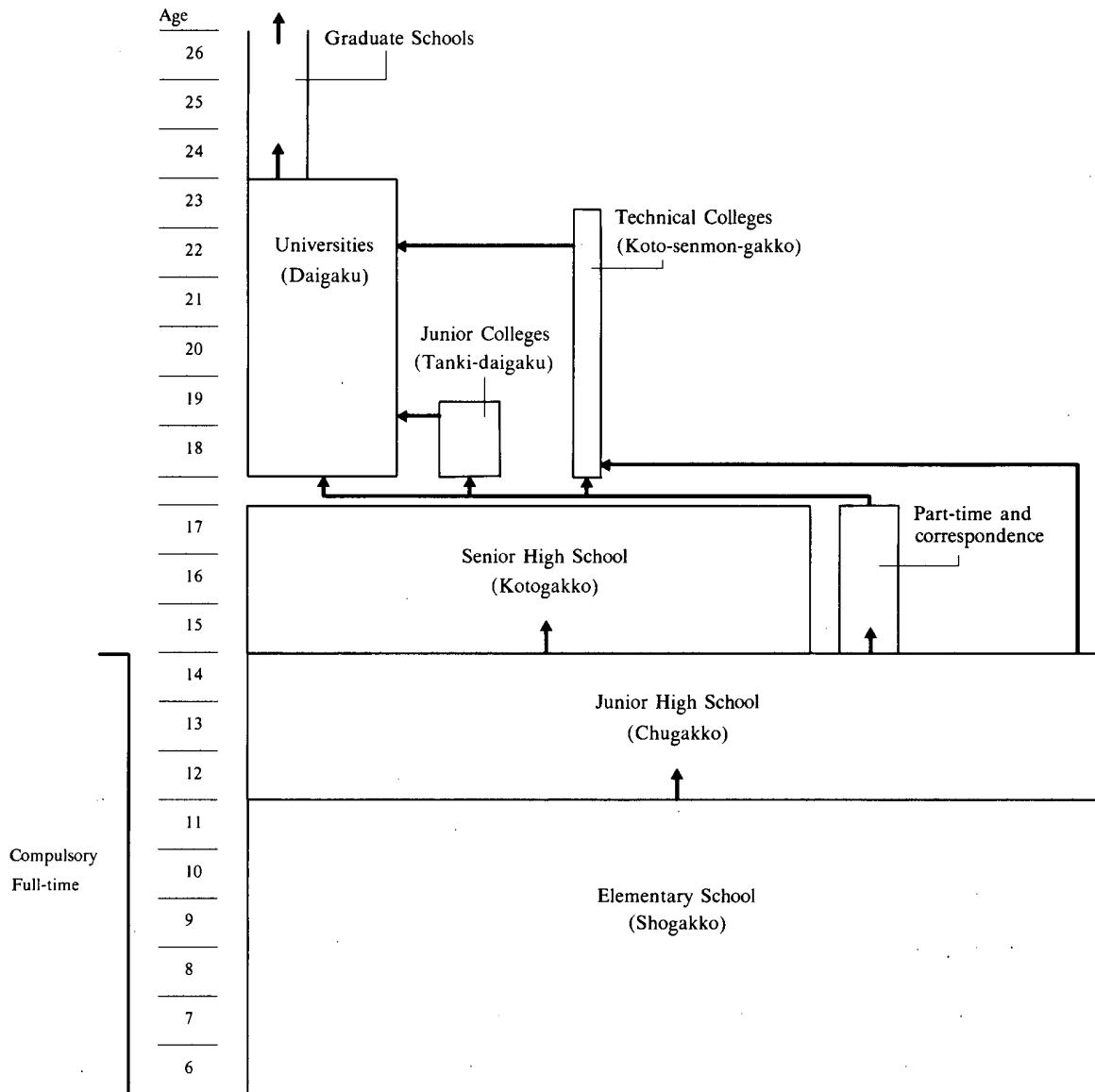
Once admitted to one of Japan's 455 universities, however, the pressure is relaxed. Classes are less intense and, since jobs are determined more by the rank of the university attended than academic performance while enrolled, students spend more time on sports and social activities. Bachelor degrees usually take four years to complete, but may take as long as six. [REDACTED]

Students who fail entrance exams or choose not to attend a university may enroll in a junior college—there are 526 of them—or in one of 62 technical schools throughout the country. Nearly one-third of Japanese students in higher education attend one of these types of schools, but more than 90 percent of junior college students are females taking some type

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Figure 4
Education in Japan, 1983



Source: *Japan Statistical Yearbook, 1983.*

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of home economics program. Students occasionally enter the five-year technical colleges directly from junior high school. Technical school graduates may be admitted to upper division university courses, but few have the temerity to attempt them. [REDACTED]

University graduates seldom continue on to graduate study in Japan. In 1982, for example, fewer than 20,000 students obtained master's and doctoral diplomas, although nearly 400,000 students graduated with bachelor's degrees. One reason is that only about half of the universities offer postbaccalaureate training. Although masters' programs have become more popular in the past 10 years, particularly in science and engineering, doctoral programs are unpopular because businesses prefer hiring and training bachelor's degree holders; a doctorate does not ensure a significantly higher starting salary. [REDACTED]

West Germany. Compulsory education in West Germany begins with Volksschule or primary school at age 6. After four years of instruction in basics, students are channeled into either the Hauptschule, Realschule, or the elite Gymnasium for more differentiated training. This decision—made when the pupil is 10 or 11 years old—is pivotal in determining the occupation and social status of the individual throughout his life. Until recently, only those students who received the Abitur—the leaving certificate for academic secondary school—were permitted to enter the universities and thus, eventually, academic and professional employment. It is now possible for students to transfer from vocational to academic secondary training, or to compete for university entrance without an Abitur. [REDACTED]

Nearly 40 percent of all primary pupils enter Hauptschule for five and sometimes six years. Afterwards, graduates are directed into either vocational training programs or part-time employment, although all youth must continue to attend vocational school at least one day a week until they are 18 years old. Hauptschule is viewed by educators as an extension of primary school and offers a relatively limited range of academic courses. More than 60 percent of Hauptschule enrollees come from blue-collar families. [REDACTED]

Realschule, or middle school, is more academically oriented than Hauptschule, but the two are more

closely related to one another than either is to the Gymnasium. The intermediate certificate enables graduates to enter the upper level of Realschule, which consists of full-time specialized technical schools. Although most intermediate-level graduates begin apprenticeships or jobs at age 16, those who successfully complete the advanced training may go on to one of the polytechnic colleges or even to a Gymnasium. The incidence of continued education among graduates depends on the Laender. According to a recent survey, for example, 17 percent of Realschule graduates in Rhineland-Palatinate transferred to Gymnasien, and 20 percent went on to full-time vocational schools, while only 3 percent of Bavarian students went to Gymnasien and 16 percent attended technical schools. [REDACTED]

Hauptschule and Realschule students holding apprenticeships or part-time jobs form what is called the dual system of education and on-the-job training. The system also has a dual fiscal nature in that the Laender establish and finance the part-time vocational schools while private firms support the apprenticeships and part-time jobs. The student's training is usually very job specific because of the unequal time spent at the workplace (about 4 to 1), and the job usually becomes permanent after graduation; this system thus encourages low mobility among West German workers. [REDACTED]

Gymnasien, the preparatory schools for the universities, are principally oriented toward either classical languages, modern languages, or mathematics. Ninth and 10th graders in North Rhine-Westphalia, for example, are required to take 11 hours of languages and fine arts each week and eight hours in science and mathematics; students in Lower Saxony must attend 15 hours each week in languages and eight in scientific subjects. The number of elective hours is correspondingly higher in North Rhine-Westphalia. The Gymnasium curriculum is a demanding one and successful completion of the exit examination, the Abitur, is the only requirement for entrance to a university. [REDACTED]

The West German system of higher education consists of 61 universities, 27 university-like institutions, 26 art academies, and 115 polytechnic colleges as of

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1980. Unlike Japan and France, no particular prestige is attached to individual universities. Universities place quotas on numbers of students, and applicants are ranked according to their Abitur scores and the length of time spent on the waiting list. The average length of study is currently more than six years at universities and a little under four years at polytechnics. [redacted]

University programs are loosely structured and embody to some extent the notion of *Freiheit des Studiums*, the freedom to design one's own course of study. In the polytechnic colleges, however, the programs are more structured and the focus of the majority of the student body—60 percent in 1980—is on engineering and technical studies. Academic degrees include the *diplom* which takes about four or five years; the *Magister Artium* which takes another two years; the *Promotion* or *Doctorat*, the equivalent of a Ph.D. in the United States, requires another four or five years; and the *Habilitation*, which requires a second major thesis (approximately another five years) and enables the recipient to be considered for appointment as a university professor. [redacted]

France. Education is compulsory in France from age 6 through 15. Five years of elementary school emphasizing the basic subjects is standard for all pupils. Secondary school is divided into two sections, or cycles, with special programs within each cycle leading to certificates of technical aptitude or competence. The type of school chosen at the beginning of the second cycle at age 15 is crucial in determining a student's career path. The route to higher education is normally through the academic secondary schools and the subsequent earning of the *baccalaureat* at age 17 or 18 on a competitive nationwide examination. Advanced degrees may be earned at general universities, technical institutes, or the prestigious *grandes ecoles*. [redacted]

Phase I of secondary school is largely standardized, although some program diversification may occur at the end of the second year. Students opting for the short second cycle may take preapprenticeship classes or abbreviated programs leading to the Certificate of Professional Aptitude (CAP). After completing the

first cycle—equivalent to intermediate school—students are examined for the *brevet des colleges*, which was originally intended as a final diploma for those not continuing their education. [redacted]

During the second phase of secondary school, students are presented with several options:

- Full-time apprenticeship training.
- Part-time work and study.
- Specialized technical training for employment at age 18.
- Preparation for entrance to a university or other institute of higher learning.

The long secondary school option includes either classical, modern, or technical training at lycees—rigorous preparatory schools similar to *Gymnasien* in West Germany—which lasts for three years. The normal completion hurdle is the *baccalaureat*, an examination given each spring, which is passed by about two-thirds of those taking it. Students may repeat the “bac” several times. The *baccalaureat des techniciens* or *brevet des techniciens* degrees are earned at technical lycees. The short secondary school option includes training at CEGs and CETs, general and technical schools, which confer clerical or technical certification and lead directly to employment after graduation. [redacted]

Higher education at universities consists of three stages. The first is a two-year program leading to the DEUG, the general university diploma. An additional year of training is required for the *licence* in literature and some sciences, and two years are necessary for the *licence* in most sciences, law, and economics. Another year beyond the *licence* for the *maitrise*, a master's degree, completes stage two and fulfills the prerequisite for entry into the final research phase. The third-cycle *agregation* can be earned in one year, a *doctorat* of the third cycle can be earned in two with a short dissertation, but the more difficult and prized *doctorat d'etat*, the highest academic degree offered, may take 10 years to achieve. [redacted]

The *grandes ecoles* are higher professional schools that confer a special status to their graduates along with the *Diplome d'etudes Superieur*. Two years of

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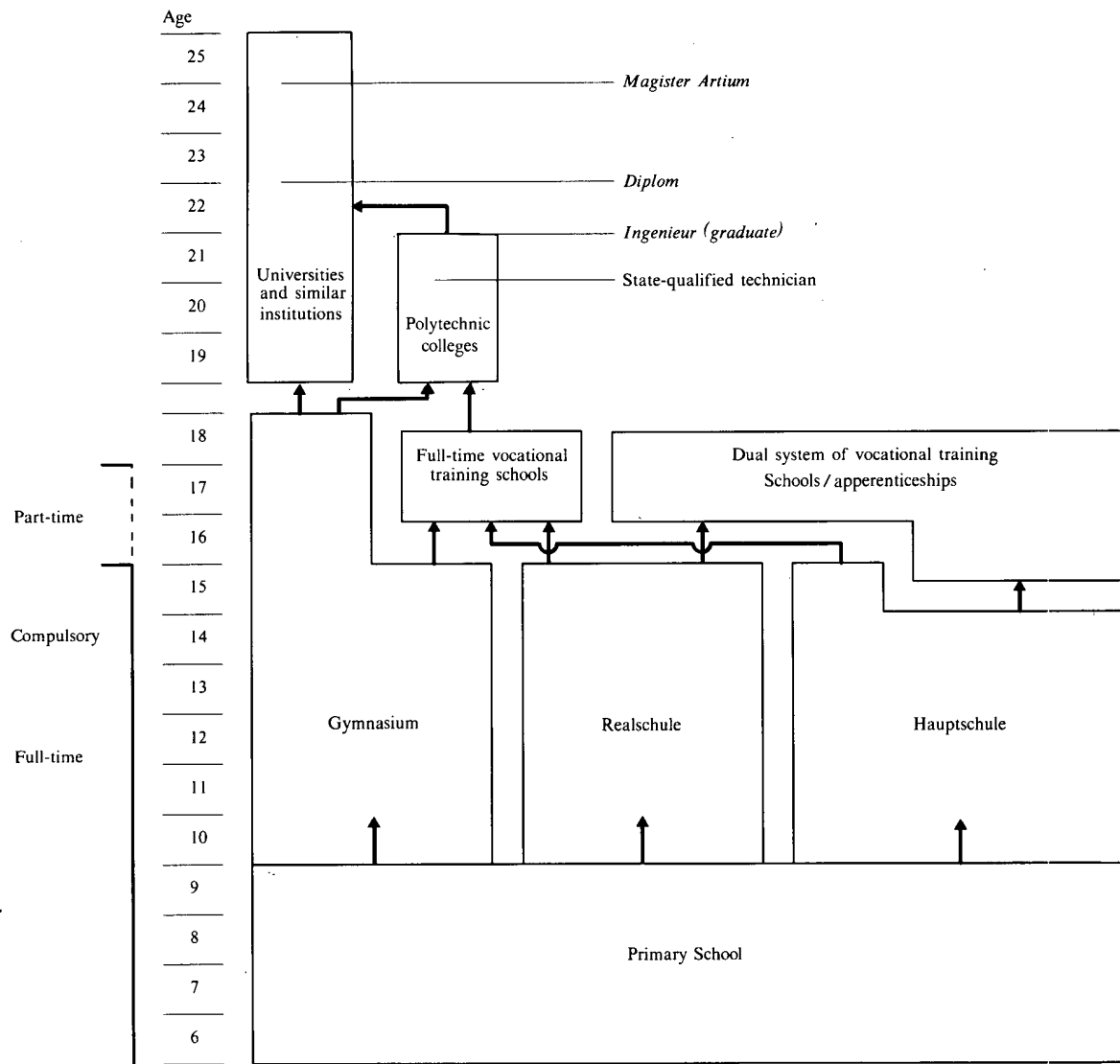
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Figure 5
Education in West Germany, 1983



Source: *Statistisches Jahrbuch, 1983.*

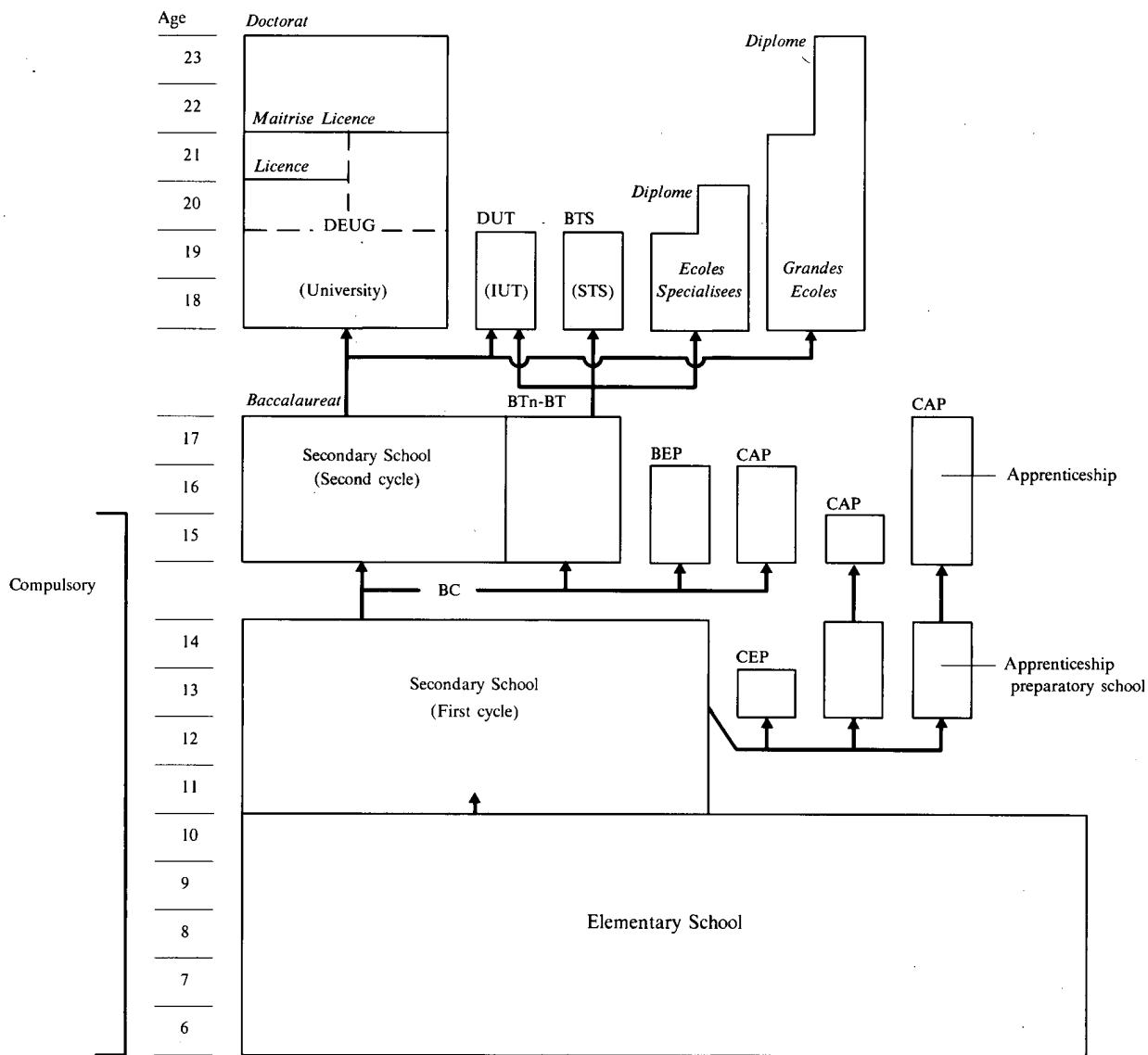
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Figure 6
Education in France, 1982^a



Source: *Annuaire Statistique de la France, 1983.*

^a Index of abbreviations:

DEUG - diplome d'etudes universitaires generales
 DUT - diplome universitaire de technologie
 IUT - institut universitaire de technologie
 BTS - brevet de technicien superieur
 STS - section de technicien superieur

BTn/BT - baccalaureat de technicien/brevet de technicien
 BEP - brevet d'etudes professionnelles
 CAP - certificat d'aptitude professionnelle
 BC - brevet de colleges
 CEP - certificat d'education professionnelle

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postsecondary preparation is usually required for the entrance exams and less than one-tenth of those who apply are admitted. Among the better known are the *Ecole des Mines* and the *Ecole Polytechnique*. The majority of these institutions are geared to producing scientists, engineers, and high-grade technicians, and the most elite of the *grandes ecoles* are viewed as proving grounds for senior staff in government and industry. [REDACTED]

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Other institutes available to French students with baccalaureates and some of the technical certificates are the national polytechnics (UER), the institutes of technology (IUT), and the engineering schools (ENSI, INP). These schools typically last two or three years and confer technical diplomas or certificates on their graduates. For the school year 1981/82, more than 10 percent of France's university enrollment was in these specialty institutes. [REDACTED]

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